Numerical Studies of Acoustic Particle Velocity, Acoustic Variability with a SSF/PE Model, and 3-D Effects of an Improved 2-D Acoustic Ray Algorithm

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LONG-TERM GOALS

The calculation of underwater acoustic pressure fields using numerical models has been at the core of numerous projects related to both sonar and environmental applications. This varies from simple sonar "range-of-the-day" predictions to the inversion of acoustic data for determination of bottom ocean properties. Although great progress has been made with existing models that compute the acoustic pressure field, much of the previous work has ignored other aspects of the propagation, such as the additional information available in the associated acoustic particle velocity fields, the impact of environmental uncertainty on sonar predictions, and the effects of 3-D environmental variability. The goal of this 2-year project is to examine these issues and determine how they may be utilized to improve performance for a variety of applications.

OBJECTIVES

The objectives of this first year's effort were to expand existing modeling capabilities to

(1) provide calculations of the unique characteristics of the acoustic particle velocity field,

(2) directly compare this with analytical predictions,

(3) examine the field behavior in range-dependent environments, and

(4) investigate properties of the vector fields on basic signal processing algorithms.

Calculations of acoustic particle velocity were made in generic ocean environments in an attempt to understand what features of the particle velocity field may be unique and exploitable. By developing intuition on the nature of the velocity field, new algorithms for sonar systems or environmental monitoring may be developed.

APPROACH

For this work, a previously developed technique for computing acoustic particle velocities from a PE model [1] was implemented in the current MMPE model [2]. This model was used to compute particle velocity fields in a variety of littoral environments of interest for a range of source parameters. The solutions were found to be generally complex, and so more fundamental calculations were performed.

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14. ABSTRACT **The calculation of underwater acoustic pressure fields using numerical models has been at the core of numerous projects related to both sonar and environmental applications. This varies from simple sonar ?range-of-the-day? predictions to the inversion of acoustic data for determination of bottom ocean properties. Although great progress has been made with existing models that compute the acoustic pressure field, much of the previous work has ignored other aspects of the propagation, such as the additional information available in the associated acoustic particle velocity fields, the impact of environmental uncertainty on sonar predictions, and the effects of 3-D environmental variability. The goal of this 2-year project is to examine these issues and determine how they may be utilized to improve performance for a variety of applications.**			
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Analytical formulations were then developed for simple environments to confirm the field behavior and the model results. The field behavior of both the vector velocity and vector intensity were investigated. More general fields were then examined utilizing basic beamforming techniques.

WORK COMPLETED

The theoretical development of the PE model approach to computing complex particle velocity fields was completed and incorporated into the MMPE model. The behavior of the velocity field in terms of angles of energy flow was considered for a Pekeris waveguide of depth 150 m with a point source transmitting at 500 Hz. The complicated interference pattern and ambiguous energy flow directions motivated an examination of the field in terms of normal modes. This further prompted analysis of the influence of multipath effects on the vector field and associated directions of energy flow. Further PE calculations were then used to show the influence of bandwidth and multipath resolution on arrival angle determination. Basic beamforming analysis was employed to illustrate the fundamental nature of the velocity field vice the vector intensity field for determining direction of energy flow.

RESULTS

The calculations of the acoustic velocity field were found to be relatively straightforward. The range and depth derivatives are needed in the (r,z)-plane of propagation. The depth derivative is trivial with a model that computes the solution over all depths. For the range derivative, one can simply employ the propagator function utilized in the pressure propagation code itself. Comparisons with analytical solutions showed good agreement.

The initial analysis of the PE model approach to computing complex particle velocity fields examined the solution in a simple, Pekeris waveguide (150m depth, 1500m/s waveguide over 1600m/s bottom, density ratio 1.2, 500Hz CW source at 60m). Figure 1 displays the typical pressure TL field as well as the magnitudes of the horizontal and vertical components of particle velocity.

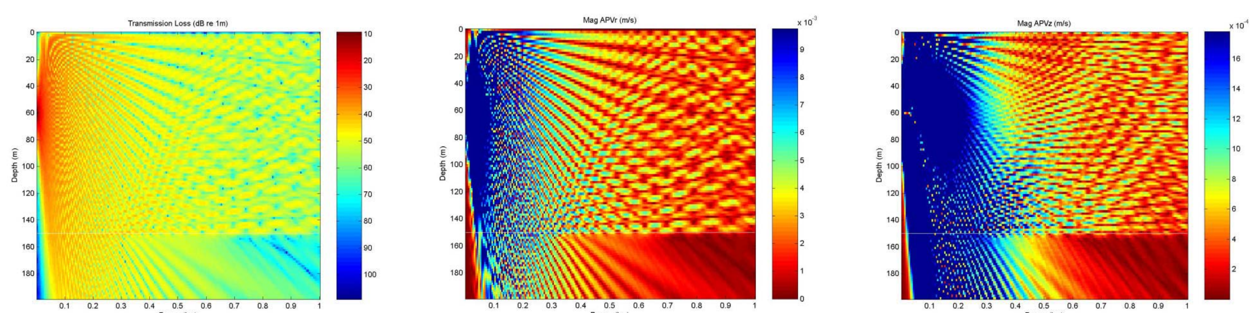

Figure 1: Pressure TL for 500 Hz source in Pekeris waveguide (left), and the associated horizontal (center) and vertical (right) component velocity magnitudes.

In Fig. 2, the angles of particle motion, as defined by $\tan^{-1}\left(\mathrm{Re}(v_z) / \mathrm{Re}(v_r) \right)$, is displayed. Although we normally consider energy propagating at angles less than critical out at the maximum range of this calculation, we find particle motion in all directions ranging +/- 90^o.

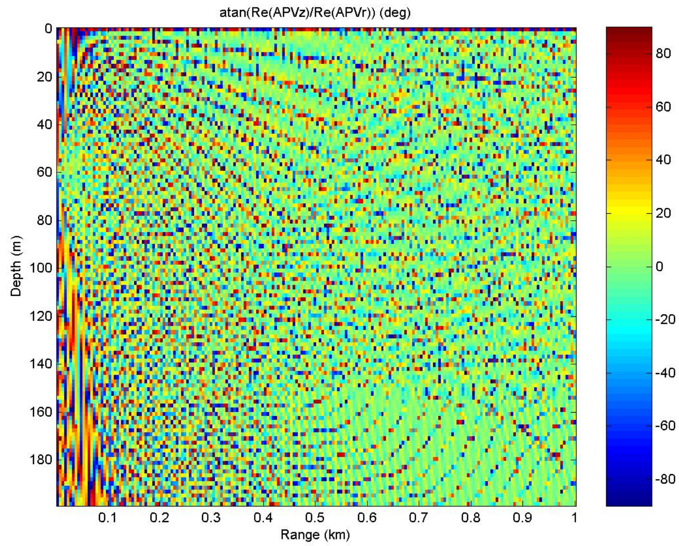

Figure 2: Ratio of real parts of vertical to horizontal components of vector velocity to determine angles of particle motion in the field.

In order to understand the details of this further, a normal mode starter was used to generate a single mode source. Again, figures displaying pressure TL and magnitudes of velocity components for mode 5 in this waveguide are displayed in Fig. 3.

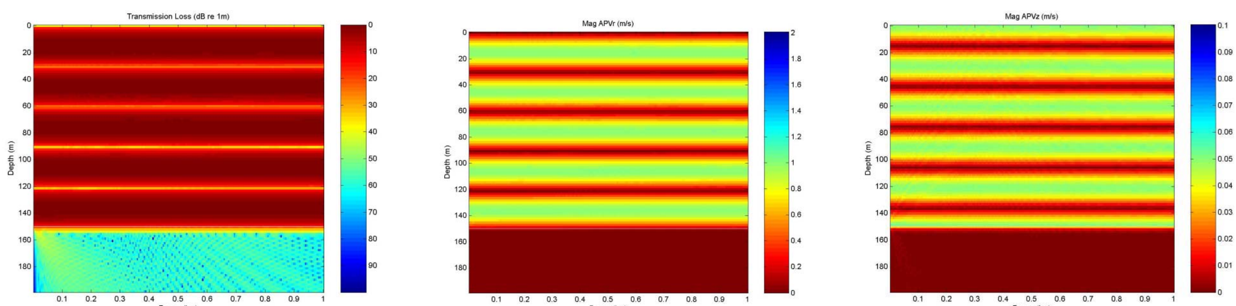

Figure 3: Pressure TL for 500 Hz, single mode 5 source in Pekeris waveguide (left), and the associated horizontal (center) and vertical (right) component velocity magnitudes.

Again, the angles of particle motion are computed and displayed in Fig. 4. Although modes are composed of energy propagating at two distinct angles (+/- θ_M), the particle velocity still shows all angles of motion.

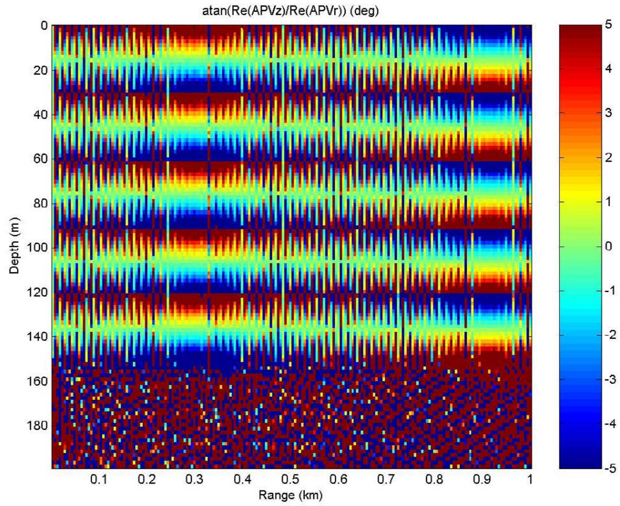

Figure 4: Ratio of real parts of vertical to horizontal components of mode 5 vector velocity to determine angles of particle motion in the field.

This led to the observation that multipath interference precludes the unambiguous determination of energy flow in an acoustic vector field at a *single* vector sensor location. As examples, broadband and narrowband PE calculations were done, and the instantaneous vector intensity was calculated for the arriving signal on a vertical array. Figure 5 displays the results for the broadband source that resolves most multipath structure.

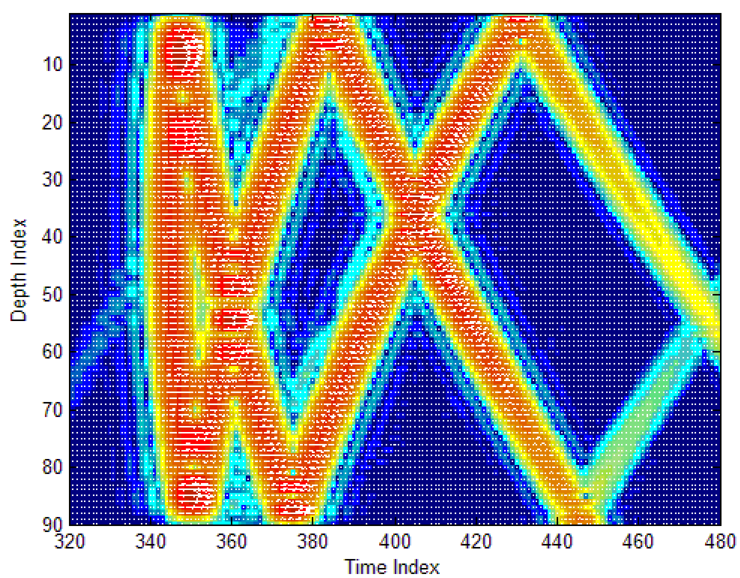

Figure 5: Broadband (512Hz centered at 500Hz) pressure TL arrival structure at 1km for Pekeris waveguide. Instantaneous acoustic intensity vectors displaying direction of energy flow are superimposed.

A simple thresholding algorithm was employed to extract angle information at high signal levels. This was applied at a depth of 25m, and the results are displayed in Fig. 6. The arrival angles are generally resolved in this case.

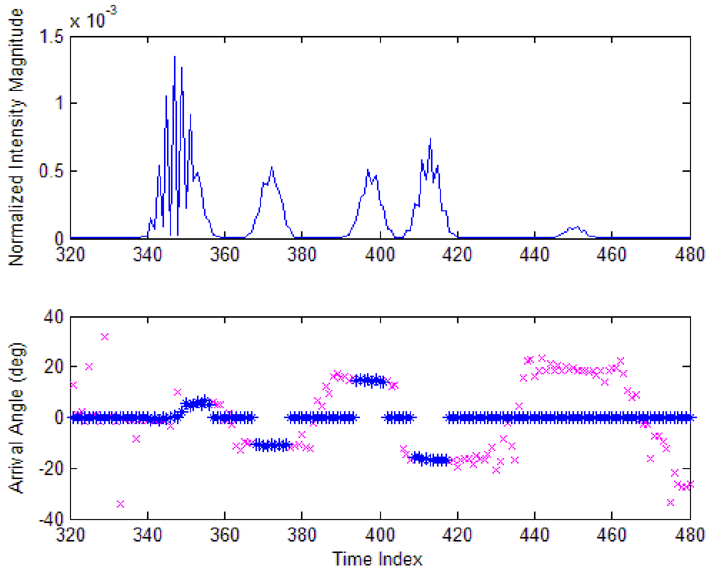

Figure 6: Broadband results of arrival angle extraction algorithm for a single vector sensor. Upper plot shows acoustic intensity magnitude. Lower plot displays angles computed from ratios of intensity components (in blue for signal exceeding threshold).

The narrowband arrival pattern is displayed in Fig. 7, and the corresponding angle extraction results at a depth of 25m are displayed in Fig. 8. Here the results are completely ambiguous, and the response of the single vector sensor provides no information on the direction of energy flow in the field.

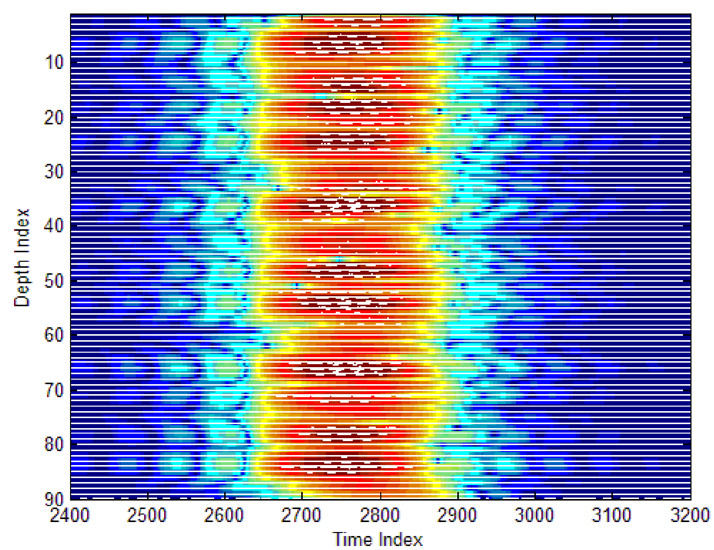

Figure 7: Narrowband (16Hz centered at 500Hz) pressure TL arrival structure at 1km for Pekeris waveguide. Instantaneous acoustic intensity vectors displaying direction of energy flow are superimposed.

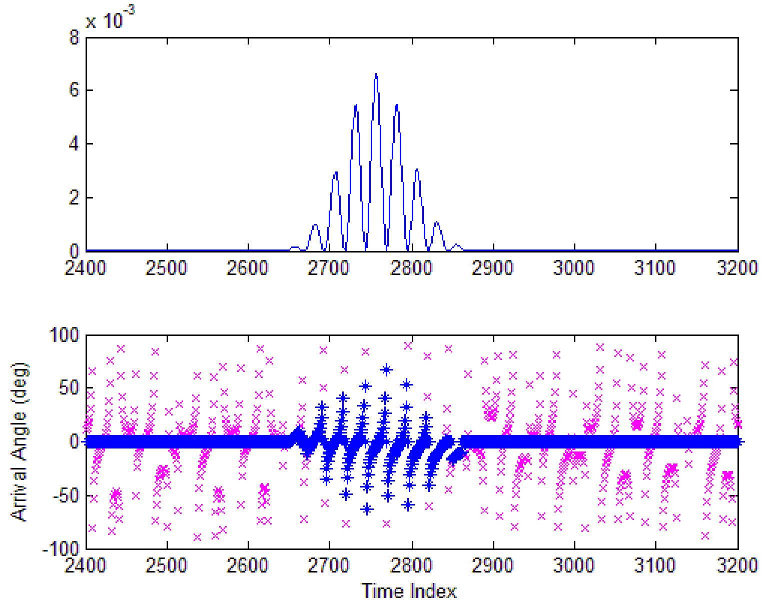

Figure 8: Narrowband results of arrival angle extraction algorithm for a single vector sensor. Upper plot shows acoustic intensity magnitude. Lower plot displays angles computed from ratios of intensity components (in blue for signal exceeding threshold).

Recent analysis has shown that the information on multipath propagation angles can still be extracted in the presence of multipath interference, but beamforming (or more general mode-forming) is required over an array of sensors. Furthermore, it was shown that such array processing should be performed on the fundamental pressure+velocity fields, and not on the directional intensity vectors (due to the loss of phase information).

IMPACT/APPLICATIONS

In this work, a succesful model for computing acoustic vector field quantities in range-dependent environments was generated. This provides a model for future, numerical investigations into features of the field and how it may be utilized/exploited in various sonar applications (e.g., acoustic comms, barrier detection, etc). It was also shown how the vector field may become more complicated than expected in the presence of multipath interence, and how an array of vector sensors are still required to resolve angles of energy propagation. Furthermore, standard array processing only applies to the fundamental acoustic quantities (pressure and particle velocity) rather than the vector intensity.

RELATED PROJECTS

Work on the modeling of acoustic vector fields in range-dependent shallow water environments is also being carried out by Bill Siegmann (RPI).

REFERENCES

1. Smith, K.B., D'Spain, G.D., and Hodgkiss, W.S., "Modeling acoustic particle velocity in range dependent environments with a parabolic equation code," J. Acoust. Soc. Am., Vol. 94, pp. 1885, 1993.

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PUBLICATIONS

Smith, K.B., "Modeling and multipath phenomenology of acoustic particle velocity fields in shallow water environments," J. Acoust. Soc. Am. [submitted Oct 2005]